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LAKE TEMPERATURES

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Great Lakes-Illinois River Basins Project

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INTRODUCTION

Purpose

Knowledge of temperatures within the waters of a lake and variations in water temperature, from place to place and from time to time, yields valuable insight into such questions as density stratification, extent and effectiveness of mixing, and consequent variations in water quality.

This paper presents the results of temperature observations in Lake Michigan, a review of and comparison with recorded previous studies, and the conclusions which may be drawn concerning temperature regimes and the fate of pollutants discharged into the Lake.

Period of Study

Field observations of temperature changes in Lake Michigan began in September 1961, and continued on an intermittent basis during the winter, spring, summer, and fall of 1962. Temperature profiles were made throughout the lake at the sampling station sites (Figure 1, and Figure 1 of Special Report Number LM2). Temperature measurements were made in the deeper portions of the lake during the winter of 1961-62.

Definitions

Stratification in a lake means that its waters are divided into layers having identifiable differences in temperature, density, or other characteristics with rather sharply defined boundaries or zones of transition between layers. Thus, a lake in which the temperature was either constant or varied uniformly from top to bottom would not be thermally stratified. A deep lake in the temperate zone usually stratifies, however, especially during the summer period. Very shallow lakes rarely stratify, due to constant mixing from top to bottom by wind action. However, during prolonged calm periods in mid-summer, even shallow lakes will stratify for short periods of time. A typically stratified lake is divided into three layers: the top layer, called the epilimnion; the bottom layer, called the hypolimnion, and a zone of rapid temperature change called the thermocline. The thermocline is normally defined as any abrupt change in temperature which would indicate that there are two vertically separated masses of water. There may also be: secondary thermoclines, where more than one exists; winter thermoclines, where colder but less dense water lies over warmer but denser water; and pseudo or false thermoclines, sometimes produced by unusual local conditions.

In Lake Michigan the epilimnion varies from a few feet in thickness in late spring or early summer to over 200 feet in late fall. The thermocline normally ranges about 20 feet thick but can be over 50 feet in thickness or as little as two feet (during storm periods, as shown by studies in other lakes). The hypolimnion encompasses all the water below the thermocline.

An overturn is a descriptive term denoting vertical mixing or circulation from top to bottom of the entire lake. If the lake is shallow a complete overturn may occur. Lakes which are extremely deep or sheltered from the wind may only experience a partial or incomplete overturn. An overturn occurs when the lake is isothermal and therefore of the same density. According to Welch the thermal resistance is at a minimum and relatively light winds could cause complete circulation (1). Most lakes in the temperate zone have an overturn in the spring and fall. In Lake Michigan a fall overturn occurs when the lake begins to cool, and is characterized by the sinking and mixing of cold, dense, water from the surface, displacing the warmer and lighter water below. Cooling continues until the lake reaches the temperature of maximum density and the water mass offers little resistance to mixing from the wind energy transferred to late fall storms. Figure 2 shows the temperature-density curve for fresh water. In some deep lakes, such as Lake Michigan, the bottom portion of the lake remains permanently at the temperature of maximum density. (The temperature of maximum density of water varies with pressure and therefore with depth, being about 4°C at the surface and decreasing about 0.06°C per 100 feet of depth.) In Lake Michigan, it appears that the bottom portion of the northern basin remains at the temperature of maximum density throughout the year. This zone of constant temperature was found to extend from the 600-foot level downward during the period of observations. The level probably varies from year to year depending on the severity of the winter. A spring overturn occurs in Lake Michigan when the surface water temperature rises to 4°C and the denser surface water sinks through the less dense layers below.

Previous Studies

Five important studies on the temperatures of Lake Michigan have been published. In addition, hundreds of observations are being taken every day at water intakes by the plant operators. The bulk of this data normally is not published and not readily accessible for general use. Several thousands of observations have been made over the past 15 to 20 years by research groups or other interested agencies for application to other problems, such as biological studies. The U.S. Navy made observations during World War II in its

submarine tests in Lake Michigan (2). The Great Lakes Research Institute of the University of Michigan and the U.S. Bureau of Commercial Fisheries at Ann Arbor, Michigan have collected and filed several thousand temperature soundings.

The five principal published studies on Lake Michigan are: Van Oosten, Church, Millar and Ayers, et al. (3)(4)(5)(6)(7) Van Oosten carried out most of his work in 1930-32 but the data was not published until 1960 (3). The work by Church in the 1940's is probably the most comprehensive published to date, covering all seasons of the year (4)(5). Millar's studies were for the surface waters of the lake and utilized the temperature recordings from ships' intakes. The study does not include the mid-winter period (6). Ayers et al. presented detailed temperature profiles for various sections of the lake during four synoptic cruises in the summer of 1955 (7). Van Oosten lists several of the minor published studies on temperature in Lake Michigan.

Although many studies of temperature have been made in Lake Michigan there has been a paucity of data for the winter period and specifically from the deeper parts of the lake.

METHOD OF STUDY

Instruments

The present investigation by the Great Lakes-Illinois River Basins Project utilizes a variety of instruments. The bathythermograph, reversing thermometer, hand thermometers and the temperature recorder are all being used. The bathythermograph (BT) (Figure 3) was invented and first described by Spilhaus in 1937 (8). The instrument was not generally available until the end of World War II, and even then the cost was still prohibitive for its general usage. A description of its operation and capabilities has been published (9). The most accurate of all thermometers is the reversing thermometer, often called a deep-sea thermometer. A detailed description and specifications have been reported by Welch (10). A hand thermometer, of the armored type, is used for calibration of the BT. The temperature recorder, developed at Woods Hole Oceanographic Institution, has been designed for long periods of recording, unattended, and at great depths (11).

In general, the instruments have the following ranges of accuracy:

Table 1
Degree of Accuracy of Instruments

Instrument	Range in °C
Hand Thermometer	± 1.0
Temperature Recorder	± 0.25
Bathythermograph	± 0.1
Reversing Thermometer	± 0.01

The BT is useful in obtaining a complete temperature profile, taking a few minutes of time even in 900 feet of water. The reversing thermometer can get accurate temperatures at one depth (such as a sampling depth) in a period of three or four minutes. A series of these instruments are frequently used on a single line. The temperature recorder can be placed at a specific depth and set to record the temperature every 30 minutes on a strip-chart for periods as long as six months. These recorders are mounted in conjunction with current meters.

Cruises

Since April 1962 the Project has conducted sampling cruises on Lake Michigan. These cruises are listed in Table 2. Prior to April 1962, temperature data was collected from several types of vessels, including those operated by the Project.

Table 2
Schedule of Cruises

Vessel	Dates	Operating Area
PHS	9/27/61	South Basin
PHS	10/6/61	"
USCG-26'	10/11/61	"
USCG-Woodbine	10/21/61	"
USCG-40'	10/24/61	"
USCG-40'	11/3/61	"
USCG-40'	11/8/61	"
USCG-40'	11/15/61	"
USCG-40'	11/21/61	"
USCG-36'	11/29/61	"
USCG-64'	12/21/61	North Basin
USCG-64'	1/25/62	"
USCG-64'	2/20/62	"
USCG-Mesquite	3/1/62	"
R/V Kaho	3/20-22/62	"
R/V Kaho	4/14/62	"
R/V Cisco	4/24-5/7/62	North & South Basins
R/V Kaho	4/26/62	North Basin
R/V Cisco	6/5-18/62	North & South Basins
R/V Kaho	6/20/62	North Basin
R/V Cisco	7/17-30/62	North & South Basins
R/V Cisco	8/29-9/9/62	South Basin
R/V Cisco	10/10-22/62	"
R/V Fitzgerald	10/18-11/30/62	"
R/V Kaho	10/28-11/7/62	"
R/V Kaho	11/28-12/6/62	"

RESULTS

Fall, 1961

Studies during the fall of 1961 were made only in the southern basin. This period includes data from the latter part of September through November, based on 75 temperature soundings; a representative number are shown in Table 3, 1 to 12. The inshore areas with depths to 65 feet were nearly isothermal, with surface temperatures of 15.5°C and still 15.0°C at 65 feet. The thermocline appeared sharply defined at depths up to 80 feet and less distinct at depths of 150 feet or more. With the advance of colder weather, the thermocline receded to greater depths and disappeared completely between November 16 and 20. Figure 4 shows the typical changes found in the fall of the year. Temperature soundings were selected to show representative portions of the southern basin.

Winter, 1961-62

The winter period is characterized by surface water temperatures generally below 4°C. During this portion of the year the lake surface may have a partial or a complete ice cover. There have only been a few recorded instances of a complete ice cover, once in the winter of 1935-36, and 1962-63.

The South Basin of Lake Michigan exhibited a different pattern of temperature distribution than the North Basin. The basin separation is a ridge between Milwaukee and Muskegon. In the South Basin, inshore areas out to the 100-foot depth, cooled to temperatures ranging from slightly above 0°C to 1°C, from top to bottom, see Table 3, 12 to 19. The surface layers froze, and in some cases were several feet thick. The inshore cooling occurred rapidly, and the lake was isothermal by mid-January. The central portion of the southern basin cooled at a much slower rate, essentially because of the large volume of water, and was constantly being mixed with the water from the deeper layers.

Studies off Milwaukee in the South Basin in January and February showed a pseudo or false winter-type thermocline. Under normal summer conditions the lake stratifies vertically due to the great density changes. In the winter period the density differences are extremely small. Because the density changes are small near 4°C (temperature of maximum density) some striking thermal variations can occur. The cruise on January 25, 1962 showed the inshore temperatures near 0.2°C whereas the mid-lake

temperatures were almost 2.3°C. The boundary zone between these two water masses was extremely sharp, and the warmer offshore water was found below the colder inshore water. This boundary zone suggests that lateral mixing did not occur very rapidly during this period of the year. The isothermal conditions from top to bottom in the deep part of the South Basin, at temperatures below that of maximum density, would tend to show that vertical mixing occurred throughout this basin.

Studies in the Northern Basin did not show complete mixing from top to bottom as shown for the South Basin. A series of temperature profiles in the deepest portion of the lake disclosed that a winter-type thermocline existed for most of the winter. The maximum depth of the winter thermocline was about the 600 foot level; below this the water temperature was at the temperature of maximum density. The existence of the thermocline approximately at the 600 foot level shows that mixing did not occur below this level. Mixing is known to occur to at least 600 feet. It is likely that the position of the winter thermocline varies from year to year, although the amount of variation is unknown.

The temperatures of the inshore waters and the upper layers of the North Basin were similar to those in the South Basin.

Figure 5 shows some typical winter profiles for the winter of 1961-62.

Spring, 1962

Definite dates marking the beginning or end of spring conditions are difficult to establish, because Lake Michigan is so large. It is possible that the complete spectrum of temperature ranges, from mid-winter to summer conditions, can occur at one time. Such wide variations would most likely occur in spring when the lake is warming, but would not occur in the fall. Figure 6 shows sample temperatures which typify spring conditions in the lake. The cruise of April 24 to May 7 (Table 3, 20 to 35) shows both winter and summer conditions at the same time, in different parts of the lake. The formation of a summer thermocline was observed on April 26 in 55 feet of water with surface temperatures at 6.4°C and bottom temperatures at 4.2°C. Yet, as late as May 1, a winter-type thermocline was found in the North Basin. Spring isothermal conditions still existed in the deeper waters of the North Basin on June 20.

Summer, 1962

Although summer conditions were found in the South Basin in April, the entire lake was not stratified until late July. On July 18 the bottom of the thermocline varied from 25 feet to 70 feet below the surface. Thickness of the thermocline varied from 15 feet on the 18th to 30 feet on the 20th. Secondary thermoclines were found in some portions of the lake at 115 feet on the 19th and they appeared unstable or weak. Typical profiles are shown in Figure 7 and Table 3, 36 to 75. The summer conditions continued through October when the lake had already begun to cool. Variations in thermocline conditions indicate that a great number of combinations of temperature profiles exist simultaneously. A few soundings can only describe the thermal range for a very limited locality.

Oscillations of the Thermocline

Tilting of the thermocline in Lake Michigan has been documented and reported by many observers (12). This phenomenon has also been shown for smaller lakes (13). Wind, blowing across the lake surface can strip off the warm surface layers and pile them on the windward shore of the lake. The stripping exposes the cold deeper layers on the leeward side of the lake and upwelling occurs. In addition to tilting, internal waves on the thermocline will also produce temperature oscillations. The period of internal waves may vary from a few minutes to over 17 hours. The internal waves with a period of 17 hours, are called inertial waves. The term is derived from the fact that the wave travels with an inertial period. Recent studies by C. H. Mortimer indicate that inertial waves on the thermocline can also produce conditions which simulate upwelling, but do not reach the surface (14). These waves, originally generated by wind energy, moved counterclockwise around the basin (according to Mortimer) with a period of 17.5 hours (Lat. 43° north). The wave period is a function of the latitude.

From August 8 through August 15 the Project had three temperature recorders in the lake (Figure 2 of Special Report Number LM7, position shown for May 15). The recorders were at the 30, 50, and 75 foot levels. The records from the 30 ft. and 50 ft. levels showed no significant changes, whereas the recorder at the 75 ft. level showed a pronounced wave on the thermocline. The wave was found for the entire period of record of 150 hours. The period of the wave averaged 17.5 hours and did not vary more than an hour over the 150 hours of observation. Neither the amplitude nor the velocity of the wave is known (see Figure 8). It is known that the wave did not reach the 50 ft. level at this time. The Project data, when compared to studies by Mortimer, show

a much purer wave form with little or no distortion. Mortimer's data, taken from water works intakes around the lake, is probably complicated by inshore turbulence and other factors. The direction of rotation during the August 8-15 period is not known. These data shed light on possible temperature fluctuations, frequently found at water works intakes, that do not appear to be related to wind. The inertial oscillation of the thermocline is rhythmic and will usually occur during calm periods. Upwelling (when the cold bottom water comes to the surface) or downwelling will occur when strong winds tilt the thermocline.

Observations in October 1961, from an anchored ship, showed internal waves with periods of several minutes which changed the position of the thermocline as much as seven feet in one hour.

Relationship of Study to Previous Work

Surface temperatures, in general, agreed with the observations of Millar (6). In a few instances the temperature regime of 1961-62 was different. The winter temperatures in the lake for 1961-62 were lower than those reported by Millar, whereas the mid-July temperatures were identical. The winter and spring temperatures of 1962 were generally cooler than the average conditions shown by Millar (6).

The winter temperatures reported by Church in 1941-42 were very similar to the winter of 1961-62 (4)(5). The summer season of 1942 appeared earlier and a thermocline appeared by mid-June. The lagging of the temperature pattern of the North Basin behind that of the South Basin, from spring to summer, was apparent both in Millar's and Church's work.

The results of the four mid-summer synoptic cruises by Ayers et al. are similar to the 1962 summer studies (7).

SIGNIFICANCE OF RESULTS

Temperature soundings taken during the winter of 1961 through the summer of 1962 indicated that the following conditions occur:

1. Temperature profiles show that a seasonal overturn occurs in the southern basin of Lake Michigan, whose maximum depth is about 565 feet.

2. Since the water below 600 feet in the northern basin remains at maximum density throughout the year, no evidence exists at this time to indicate that mixing (due to overturn) occurs below this depth.

3. Inshore vertical cooling and mixing occurs rapidly but the horizontal exchange with the main body of the lake appears to occur at a slower rate. The rate of exchange, vertically or horizontally, is unknown.

4. The northern basin lags thirty days or more behind the southern basin during the late spring and early summer warming period.

5. The southern basin cools at a more rapid rate than the northern basin.

6. Typical temperatures for Lake Michigan for a season or month of the year are difficult to define. The temperature range during one month varies considerably between the two basins at any one time. The temperature range for any given month may be expected to vary widely from year to year depending upon the severity of the winter or the calmness of the summer.

7. Marked changes or configurations of the thermocline from one end of the lake to the other are characteristic of summer conditions in the lake.

8. Inertial waves on the thermocline, usually occurring during calm periods following a strong wind, can produce alternating periods of warm surface water and cold deeper water at a water works intake.

9. Under certain conditions, pollutants discharged into the lake could lie on the thermocline (because of similar densities as explained in Special Report Number LM7) and be brought to the surface during the summer period, by tilting or oscillations of the thermocline.

10. Internal waves with periods of several minutes were observed to change the position of the thermocline as much as seven feet per hour.

The studies clearly indicate the great variability with respect to both location and time, of the water temperatures in Lake Michigan.

TABLE 3

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	1	2	3	4	5	6	7	8	9*
0	15.7	14.7	14.8	12.9	12.8	12.4	11.3	11.2	9.7
25	15.7	14.7	14.4	12.9	12.9	12.4	10.8	11.2	9.7
50		14.6	14.0	12.9	12.9	12.4	10.8	11.2	9.7
75		14.5	10.0	12.9	12.9	12.4	10.8	11.2	9.8
100		11.4	4.5	12.9	12.9	12.0	10.8	10.9	9.8
125		6.5	4.4	12.9	12.4	11.6	10.1	10.6	9.8
150		6.4	4.3	8.7	8.0		9.9	10.0	9.8
175			4.3	5.5	5.6		9.8	9.5	9.8
200			4.3				9.6		
300									
400									
500									
600									
700									
800									
Date	9/27/61	10/6/61	10/11/61	10/21/61	10/21/61	10/24/61	10/24/61	11/3/61	11/8/61
Time	1354	1312	1316	1125	1225	1220	1255	1245	1225
Max. Depth	31	155	210	190	190	141	212	179	192
Bottom Temp.	15.7	6.4	4.3	5.5	5.6	11.6	8.5	9.5	9.8
Basin Location	S	S	S	S	S	S	S	S	S

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	10	11	12	13	14*	15*	16	17	18
0	8.7	7.5	7.4	4.6	3.2	2.6	0.8	0.4	1.8
25	8.7	7.5	7.4	4.6	3.2	2.6	0.9	0.4	1.8
50	8.7	7.5	7.4	4.6	3.1	2.6	0.9	0.4	1.8
75	8.7	7.5	7.4	4.6	3.1	2.6	1.0	0.4	1.8
100	8.7	7.5	7.4	4.6	3.1	2.6	1.2	0.4	1.8
125	8.7	7.5	7.4	4.6	3.1	2.6	1.2	0.4	1.8
150	8.7	7.5	7.4	4.6	3.1	2.5	1.3	0.4	1.8
175	8.7	7.5	7.4	4.6	3.0	2.5	1.4	0.4	1.8
200	7.8	7.5	7.4	4.6	3.0	2.5	1.4	0.4	1.8
300				4.6	3.0	2.5	2.1		3.0
400				4.6	3.0	2.5	3.0		3.2
500					3.0	2.5	3.1		3.4
600							3.2		3.5
700							3.2		3.6
800							3.3		
Date	11/15/61	11/21/61	11/29/61	12/21/61	1/25/62	2/20/62	3/1/62	3/20/62	3/22/62
Time	1206	1150	1304	1445	1503	1512	1540	2033	1730
Max. Depth	214	220	209	462	500	500	800	-	760
Bottom Temp.	7.6	7.5	7.4	4.6	3.0	2.5	3.3	0.4	3.7
Basin Location	S	S	S	N	S	S	N	N	N

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	19	20*	21	22*	23*	24	25*	26*	27*
0	1.8	3.5	6.5	2.4	2.6	6.5	2.3	2.4	2.2
25	1.8	3.5	6.4	2.4	2.6	4.5	2.3	2.4	2.2
50	1.8	3.5	6.4	2.4	2.6	4.2	2.3	2.3	2.2
75	1.9	3.4		2.3	2.5		2.3	2.3	2.2
100	1.9	3.4		2.3	2.4		2.2	2.3	2.2
125	1.9	3.4		2.3	2.4		2.2	2.3	2.2
150	1.9	3.3		2.3	2.4		2.2	2.3	2.2
175	1.9	3.3		2.3	2.4		2.2	2.3	2.2
200	1.9			2.3	2.4		2.2	2.3	2.2
300	1.9				2.4		2.2	2.2	2.1
400	2.5				2.4			2.2	
500	3.1				2.5				
600	3.3				3.2				
700	3.4				3.4				
800					3.4				
Date	4/14/62	4/24/62	4/25/62	4/25/62	4/26/62	4/26/62	4/27/62	4/28/62	4/29/62
Time	1212	1347	0917	1208	1103	1008	1525	1050	1045
Max. Depth	750	190	65	-	800	55	355	-	300
Bottom Temp.	3.5	3.3	6.4	2.3	3.4	4.1	2.1	2.2	2.1
Basin Location	N	S	S	S	N	S	S	S	N

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	28*	29	30	31*	32*	33	34	35	36
0	2.0	1.8	2.2	2.7	2.8	2.2	6.0	3.3	10.0
25	1.9	1.8	2.2	2.6	2.7	2.2	5.7	3.3	8.5
50	1.9	1.8	2.2	2.6	2.7	2.2	5.0	3.3	5.7
75	1.9	1.8	2.2	2.6	2.7	2.2	4.3	3.4	
100	1.8	1.8	2.2	2.6	2.7	2.2		3.4	
125	1.8	1.8	2.2	2.5	2.7	2.2		3.5	
150	1.8	1.8	2.2	2.5	2.7	2.2		3.6	
175	1.8	1.8	2.2	2.5	2.6	2.2		3.8	
200	1.8	1.8	2.2	2.4	2.6	2.2		3.9	
300	1.8	2.1	2.2	2.4	2.6				
400	1.7	2.8	2.8	2.4	2.6				
500									
600									
700									
800									
900									
Date	4/30/62	5/1/62	5/2/62	5/3/62	5/4/62	5/5/62	5/6/62	5/7/62	6/5/62
Time	1150	1325	1435	1153	1015	1219	0916	0755	1221
Max. Depth	420	-	-	-	-	210	95	250	65
Bottom Temp.	1.7	-	-	-	-	2.8	4.5	3.7	5.5
Basin Location	N	N	N	N	N	N	N	S	S

TABLE 3 (Continued)

Representative Temperature Profiles-^{o}C

Identification Number

Depth in Feet	37	38	39	40	41	42	43	44*	45
0	9.5	5.6	7.7	10.3	10.3	10.8	11.0	4.1	11.1
25	9.5	5.3	7.0	8.6	9.7	10.7	10.9	3.9	10.6
50	5.6	4.6	5.5	7.1	6.9	9.1	8.0	3.9	7.2
75	5.5	4.4		5.4	5.8		6.7	3.8	
100		4.4		5.2	5.4			3.8	
125		4.3		5.0	5.0			3.7	
150		4.2		4.9	4.6			3.7	
175		4.2		4.7	4.3			3.7	
200		4.1		4.6	4.1			3.7	
300		3.8		4.0				3.6	
400								3.6	
500									
600									
700									
800									
Date	6/6/62	6/6/62	6/7/62	6/8/62	6/9/62	6/10/62	6/11/62	6/12/62	6/13/62
Time	0805	1120	1258	1350	0905	1300	1102	1113	1346
Max. Depth	80	345	50	340	250	50	95	-	50
Bottom Temp.	5.8	3.8	5.5	3.9	3.9	9.1	5.5	3.6	7.2
Basin Location	N	N	N	N	N	N	N	N	N

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	46	47	48	49	50	51	52	53	54
0	14.6	18.0	6.6	17.3	17.2	4.2	16.7	20.2	21.4
25	11.2	16.9	5.6	16.9	16.7	4.2	16.0	20.0	21.3
50	10.0		5.3	15.7	15.0	4.2	6.2	8.3	20.4
75	6.5		5.1			4.2		5.0	19.9
100	6.1		4.8			4.2		4.6	
125	6.0					4.1		4.3	
150						4.1		3.9	
175						4.0		3.9	
200						4.0		3.9	
300						3.9			
400						3.9			
500						3.8			
600						3.8			
700						3.8			
800						3.8			
Date	6/14/62	6/15/62	6/16/62	6/17/62	6/18/62	6/20/62	7/17/62	7/18/62	7/18/62
Time	1012	1009	1040	1019	0950	0950	1500	1242	1420
Max. Depth	135	40	115	65	65	830	65	240	70
Bottom Temp.	6.0	16.0	4.6	12.5	12.5	3.8	6.0	3.9	13.6
Basin Location	N	N	N	N	N	N	S	S	S

TABLE 3 (Continued)

Representative Temperature Profiles-^{o}C

Identification Number

Depth in Feet	55	56	57	58	59	60	61	62	63
0	20.5	19.9	17.9	19.0	17.2	17.5	20.8	15.0	15.0
25	19.8	19.7	17.8	18.9	16.9	16.5	20.8	14.9	10.0
50	17.5	10.0	14.4	13.0	12.8	10.1	10.0	14.5	8.7
75	8.2	5.7	8.9		5.6		5.6	4.6	6.6
100	6.7	5.4	6.4		5.0		5.1	4.3	
125	4.5	4.6	5.2		4.9		4.7	4.2	
150	4.5	4.4	4.6		4.7		4.4	4.0	
175		3.9	4.3		4.4		4.3	4.0	
200		3.9	4.2		4.3		4.3	3.9	
300		3.8	3.9		3.8		3.9	3.7	
400		3.8					3.8	3.6	
500								3.6	
600									
700									
800									
Date	7/19/62	7/20/62	7/21/62	7/22/62	7/24/62	7/25/62	7/26/62	7/27/62	7/28/62
Time	1021	1107	0905	0813	1150	1418	0943	1035	0959
Max. Depth	160	-	300	70	300	65	-	510	85
Bottom Temp.	4.5	3.7	3.9	11.0	3.8	8.0	-	3.6	6.5
Basin Location	S	S	S	S	N	N	N	N	N

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	64	65	66	67	68	69	70	71	72
0	17.2	20.8	18.1	18.6	18.0	18.3	17.2	17.1	16.5
25	16.9	20.7	17.8	18.2	17.8	18.0	16.7	17.1	16.5
50	16.8	20.5	17.7	18.1	17.7	17.5	16.2	17.1	16.5
75	9.4		17.6	17.8	17.7	17.3	16.1	17.1	16.4
100	5.8		11.0	10.7	14.5	15.5	11.7	17.1	6.2
125	5.1		8.6	6.3		10.7	4.9		5.5
150	4.6			6.0		7.0	4.9		5.5
175	4.2			6.0		6.7	4.9		5.5
200	3.9								5.5
300	3.8								
400									
500									
600									
700									
800									
Date	7/29/62	7/30/62	10/10/62	10/11/62	10/13/62	10/14/62	10/15/62	10/19/62	10/20/62
Time	0944	0946	1240	1343	1428	1211	1338	0840	0953
Max. Depth	350	65	142	191	113	185	190	109	-
Bottom Temp.	3.8	19.1	8.4	6.0	10.0	6.7	4.9	17.1	-
Basin Location	N	S	S	S	S	S	S	S	S

TABLE 3 (Continued)

Representative Temperature Profiles-°C

Identification Number

Depth in Feet	73	74	75
0	17.0	14.7	16.7
25	16.9	14.7	16.7
50	16.8	14.4	16.7
75	16.8	13.9	16.5
100	16.8	5.4	16.2
125	10.2	4.7	7.7
150	6.5	4.4	5.5
175	6.2	4.4	5.4
200	5.9	4.3	
300		3.9	
400			
500			
600			
700			
800			
Date	10/20/62	10/21/62	10/22/62
Time	1610	1115	1037
Max. Depth	200	320	176
Bottom Temp.	5.9	3.9	5.4
Basin Location	S	S	S

*Denser water lies on top of lighter water
S: South Basin
N: North Basin

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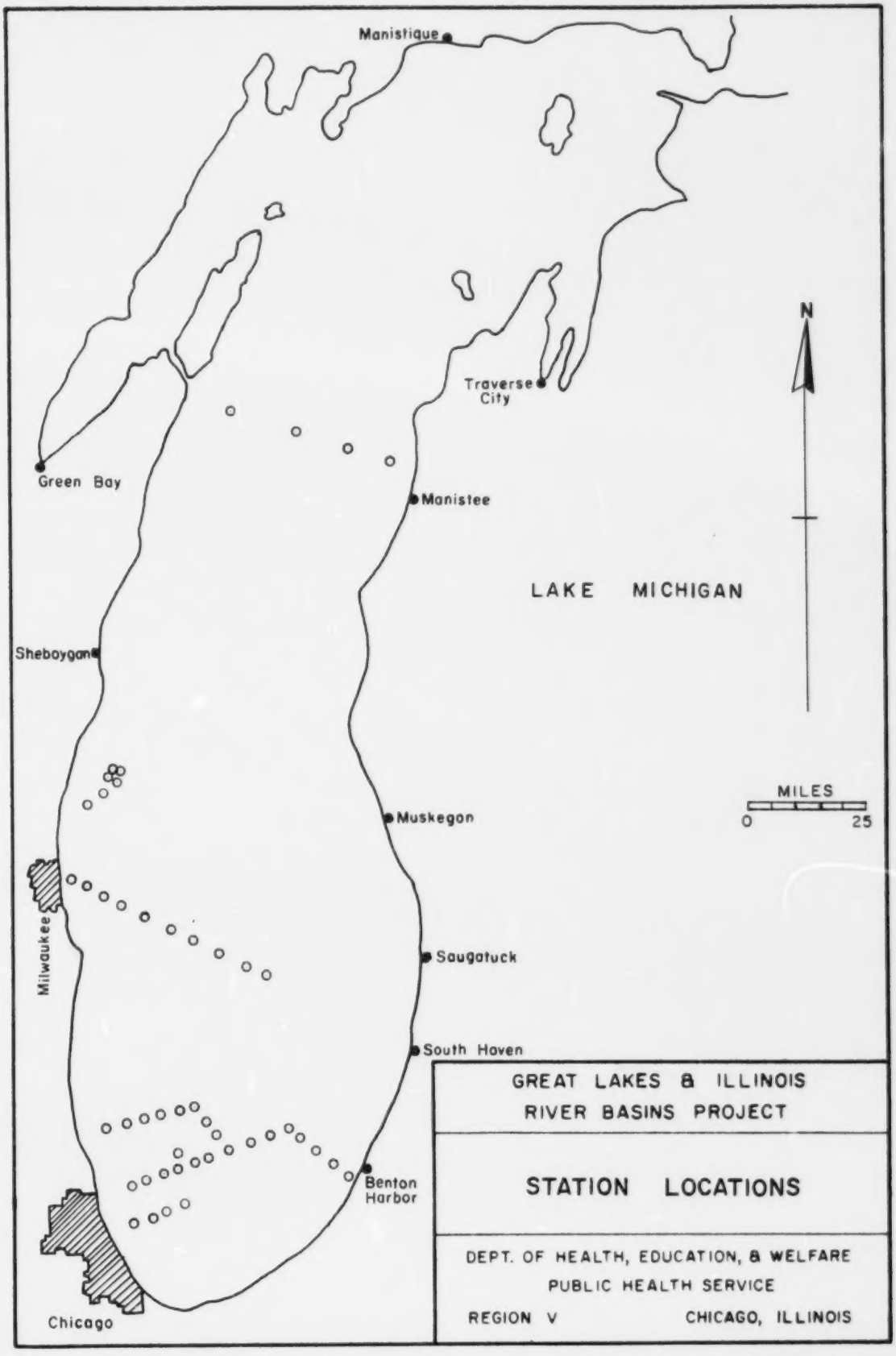
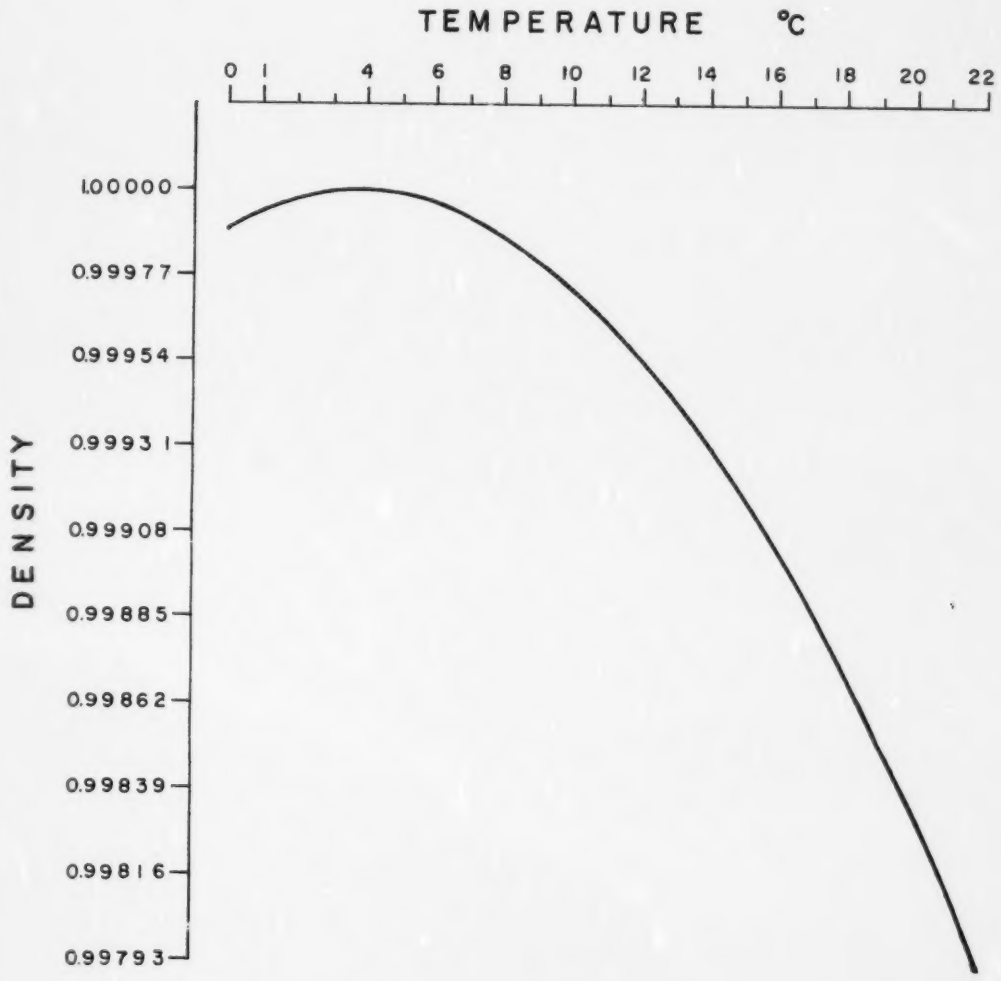

Manistique
Traverse City
Green Bay
Manistee
LAKE MICHIGAN
N
Sheboygan
MILES
0
25
Muskegon
Milwaukee
Saugatuck
South Haven
Benton Harbor
Chicago
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
STATION LOCATIONS
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 1



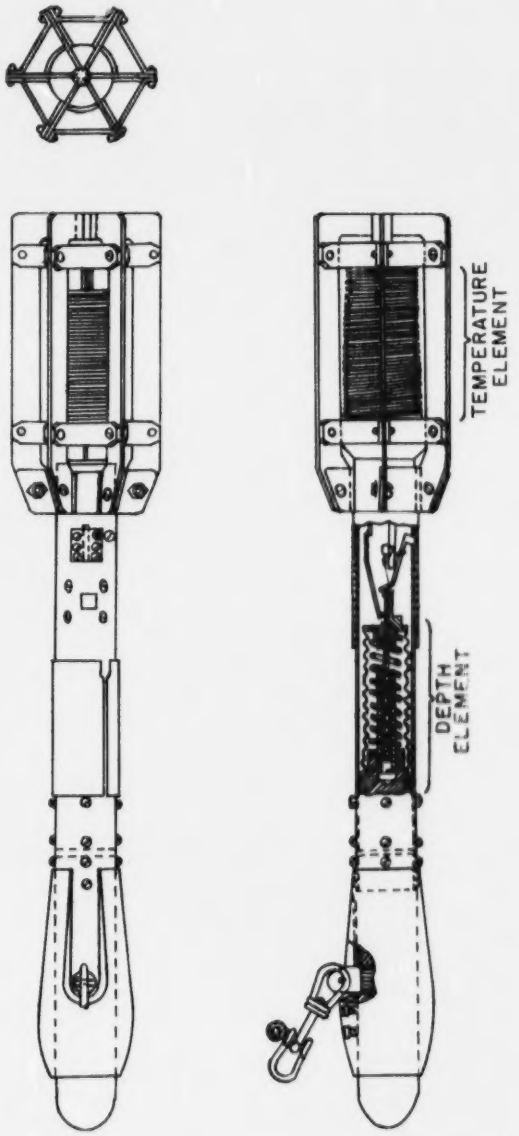
NOTE
Welch, reference 10, page 350

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

DENSITY OF FRESH WATER

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 2

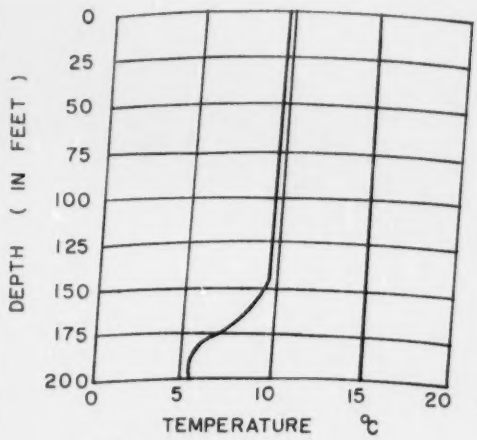


GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

THE BATHYTHERMOGRAPH

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 3



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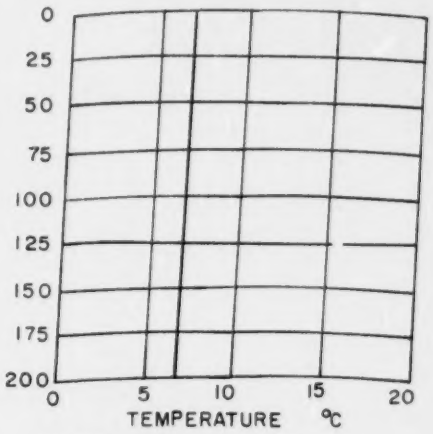

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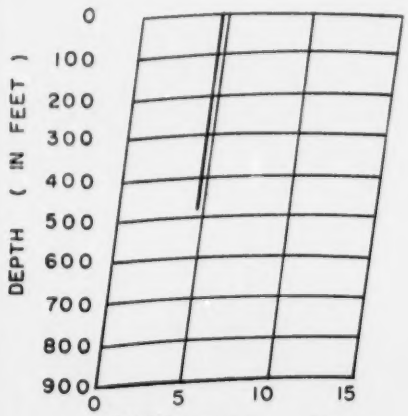


SLIDE NO.79
DEC. 21, 1961
TIME 1345 CST
BT NO. 48599

SOUTH BASIN

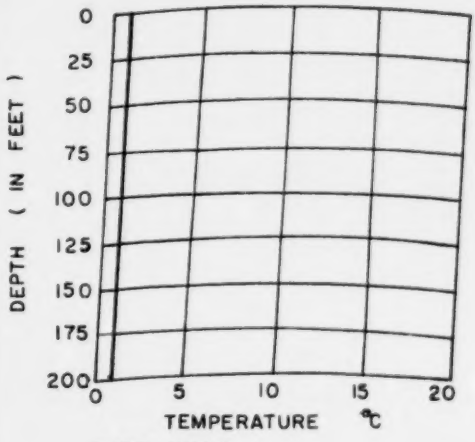
LAKE MICHIGAN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

TEMPERATURES
FALL, 1961

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 4



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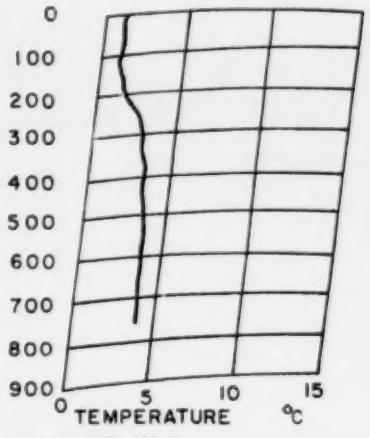
TIME 1933 CST
BT NO. 16122



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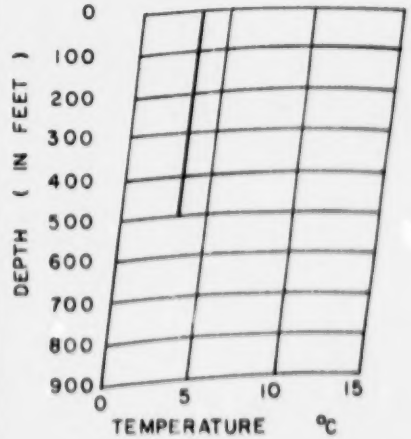
MARCH 22, 1962
TIME 1820 CST
BT NO. 1241-B



SLIDE NO. 92
JANUARY 25, 1962
TIME 1403 CST
BT NO. 48599

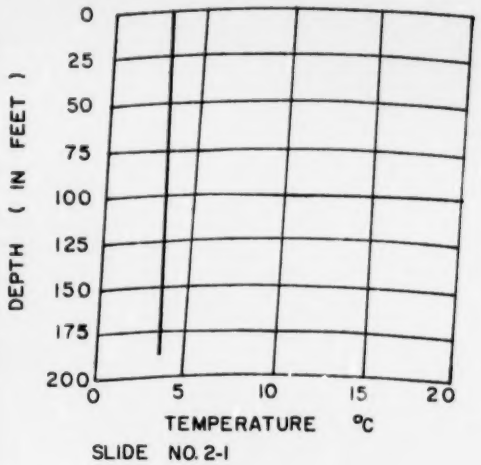
NORTH & SOUTH
BASIN
LAKE MICHIGAN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

TEMPERATURES
WINTER, 1962

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 5



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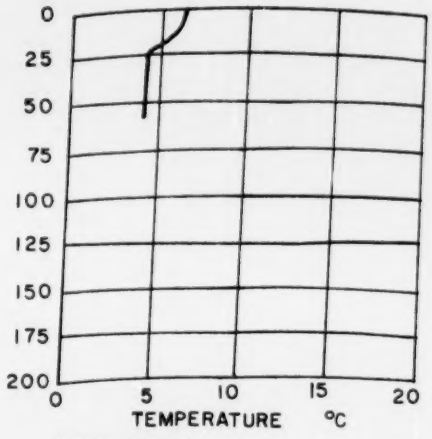
APRIL 24, 1962
TIME 1347 CST
BT NO. 5834



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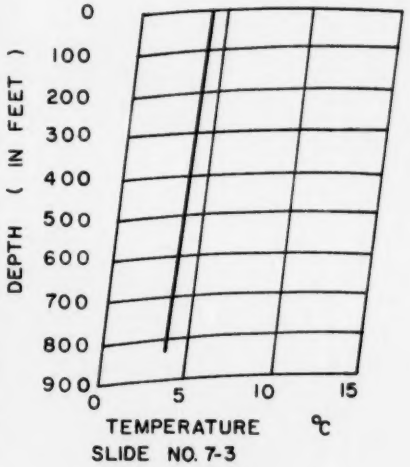
TIME 1008 CST
BT NO. 5834



SLIDE NO. 7-3
JUNE 20, 1962
TIME 0850 CST
BT NO. 1241 B

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BASIN
LAKE MICHIGAN

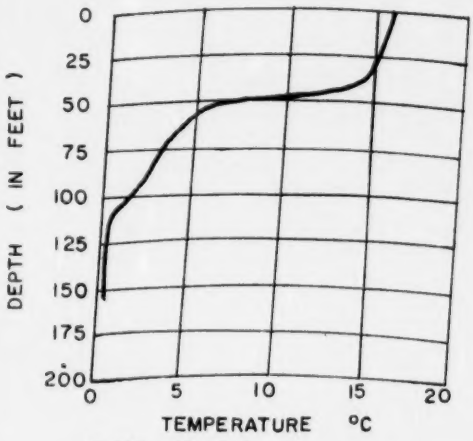
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

TEMPERATURES

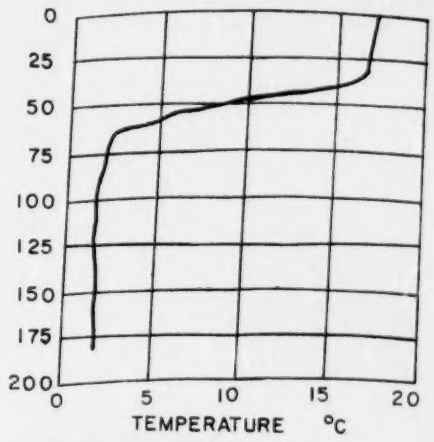
SPRING, 1962

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 6



SLIDE NO. 6B-5
JULY 19, 1962
TIME 1103 CST
BT NO. 5834



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TIME 1427 CST
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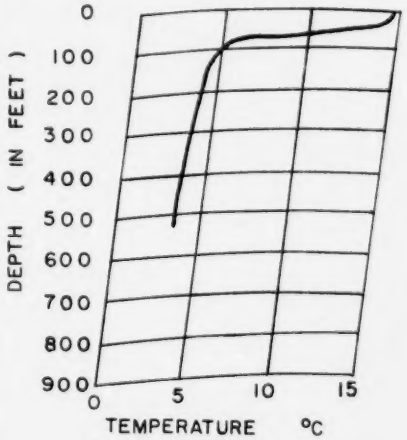

SLIDE NO. 22A-5
JULY 27, 1962
TIME 1035 CST
BT NO. 48599

NORTH & SOUTH
BASIN
LAKE MICHIGAN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

TEMPERATURES

SUMMER, 1962

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 7

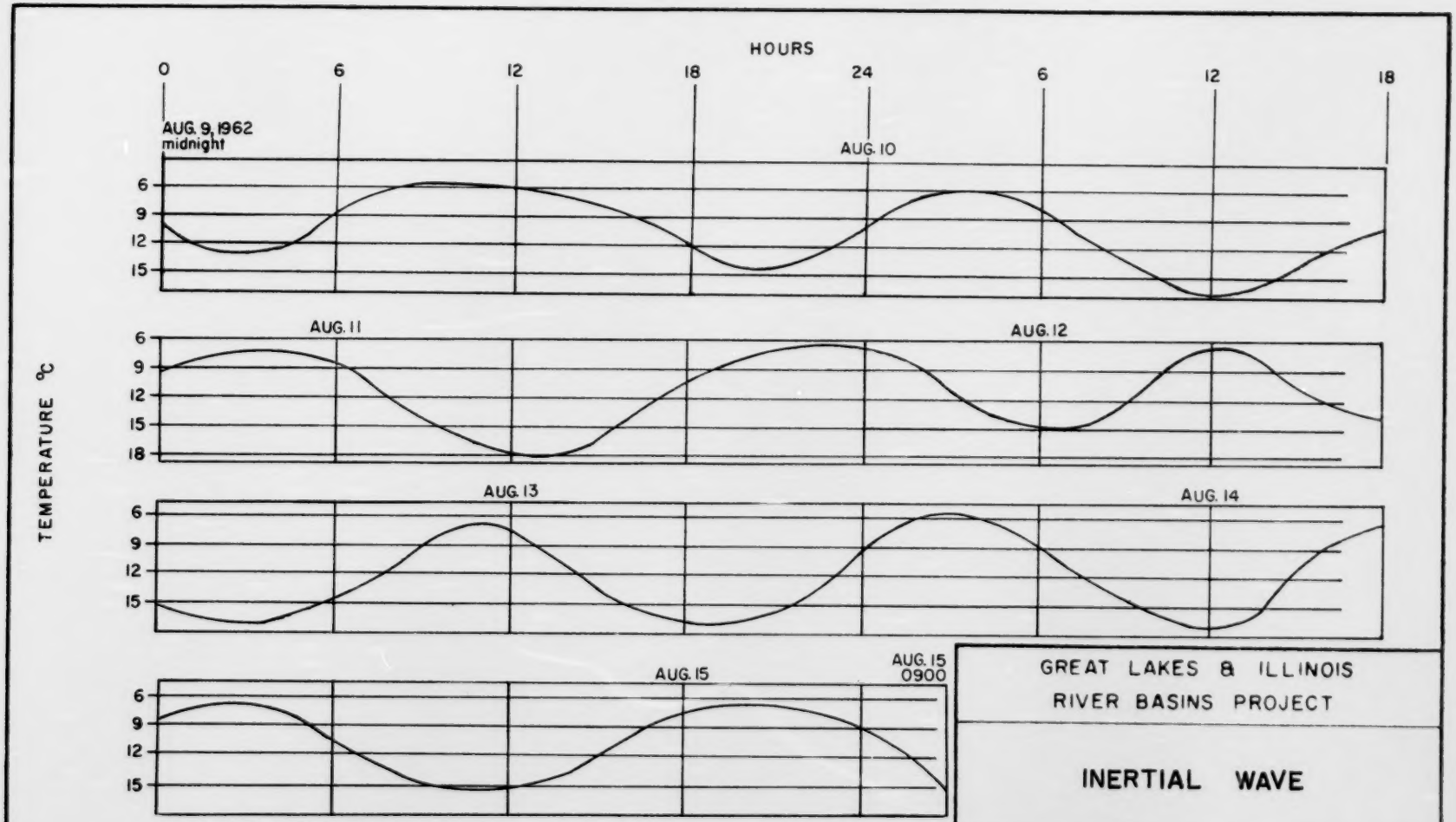
HOURS
0
6
12
18
24
6
12
18
AUG. 9, 1962
midnight
AUG. 10
AUG. 11
AUG. 12
AUG. 13
AUG. 14
AUG. 15
AUG. 15
0900
TEMPERATURE °C
6
9
12
15
18
Depth of Recorder: 75 feet
Location: 15 miles NE Chicago Harbor Light
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
INERTIAL WAVE
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 8